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The Meeting Beams of Headlights; Effects of Deterioration and Misaim

By A. J. HARRIS, B.Sc.

Summary

The most important factor in the design of the typical meeting beam of headlights, so far as the range of direct seeing is concerned, is the sharpness and form of the cut-off near the horizontal. But the effect which the cut-off will have on the likelihood of being dazzled, i.e., of being rendered incapable of seeing more than a short distance, when meeting other vehicles at night depends enormously on the accuracy with which meeting beams are aimed. The effect can be calculated when the standard of aiming is known; the basis of the calculation and some results are given in this paper. Curves are provided from which may be found the sharpness of cut-off required to give any desired level of freedom from dazzle. It is shown that if the standard of aiming is too low it will be impossible to design a beam to fulfil the required conditions. The necessary improvement in aiming can, however, be determined from the curves. The effect of deterioration in increasing the liability to dazzle is also considered. The pitching motion of the vehicle, and its effect on seeing distance and on intermittent glare, have had to be omitted from this analysis; the effect will be more important the sharper the cut-off employed.

(1) Introduction

Headlight beams must be judged by their performance in the conditions in which they have to operate—meeting beams, for instance, by how well the driver can see when meeting another vehicle Performance tests of this kind have frequently been carried out for meeting beams, but in almost all of them the lamps used have been new and have been correctly aimed. The conditions of the test have therefore been different from conditions on the road, and the tests may be misleading because they entirely omit the effects of misaim and deterioration which in practice, in England at least, are of considerable importance. These effects would remain even if, as in the United States, all vehicles were fitted with lamps of essentially the same design, for there would still be differences in the effective intensities of the beams on different vehicles and, in consequence, a driver meeting another vehicle would see well enough on some occasions and badly on others; he would also experience very different amounts of discomfort. The performance with which we are concerned is really the aggregate of the performances in the individual encounters, and in judging the suitability of a design all possible encounters should be borne in mind, particularly those in which seeing is poor. Performance, defined in this way, does not depend solely on the design of the beam itself; indeed, it is meaningless to speak of performance except in relation to a definite standard of aiming and level of deterioration. It follows therefore that the choice of beam must depend on the standard of aiming attainable and the degree of deterioration allowed. For example, a beam with a very sharp cut-off might be quite satisfactory if aiming was generally good, but if aiming was poor it would give a large proportion of short seeing distances and be intolerably dazzling. Or again, a beam of low intensity might be satisfactory if a strict standard of maintenance was insisted upon, but unsatisfactory if severe deterioration was tolerated.

The paper shows how this overall performance of a beam may be calculated when the minimum seeing distance during an encounter is taken as a measure of the per-

The author is with the Road Research Laboratory of the Department of Scientific and Industrial Research.
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The meeting beam, also called the passing beam, is a beam designed for use when two vehicles are approaching one another from opposite directions. It may be the dipped beam of the headlight system or may be emitted by special auxiliary lamps.

formance during that encounter. The relations between performance, sharpness of cut-off, and standard of aim are investigated; the effect of deterioration is also considered. Numerical results are obtained for a beam of simple design which approximates to typical modern designs in the region of the beam mainly responsible for glare and for distance seeing on the nearside of the road. These results go some of the way towards putting the design of meeting beams on a rational foundation. For example, if a certain level of performance is specified, then the necessary sharpness of cut-off and standard of aiming can be determined.

Factors which have had to be ignored in the present paper are the pitching motion of the vehicle, caused mainly by the irregularity of the road surface, and the intermittent dazzle to which it can give rise. The effect of this will be more marked on beams having a sharp cut-off.

In an earlier paper by Stiles and Dunbar[1], the effect of headlight glare was reduced to calculation, but the main object of investigation was the performance obtainable from individual lamps rather than the aggregate of performances.

(2) Seeing Under Conditions of Glare

The glare of approaching headlights reduces a driver's ability to see. By revealing as dark silhouettes any pedestrians or vehicles which may be on the road between him and the approaching vehicle, these lights may, however, at times actually assist him to see; a driver may see a pedestrian in silhouette against the illuminated road surface long before he is able to see him directly. This silhouette-seeing is sometimes of great assistance when direct seeing is poor, but it has been argued that less importance should be attached to it than to direct seeing because it is not always effective and cannot, in any case, reveal a pedestrian who does not step on to the road until the approaching vehicle has passed him. In this paper the possibility of silhouette-seeing is ignored, and discussion is confined to the performance of lamps in direct seeing.

The performance of a meeting beam in a single encounter is found by fitting two cars with identical beams and running them towards one another on a straight track on which certain objects of a standard form have been placed. By means of distance-recording mechanisms in the vehicles the drivers are able to record the distances at

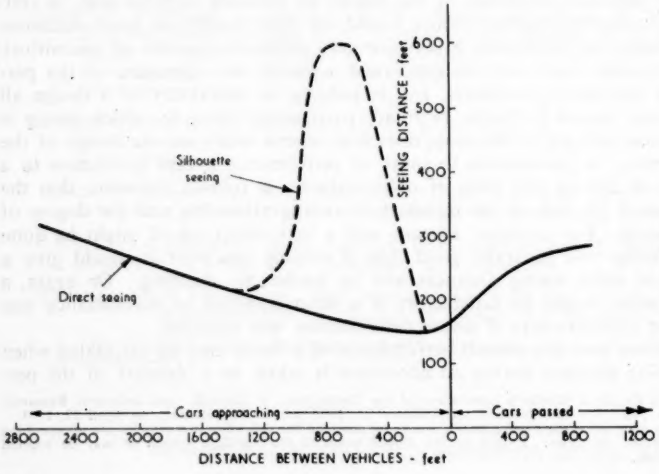

Fig. 1. Seeing distance as function of distance between vehicles (after Roper).

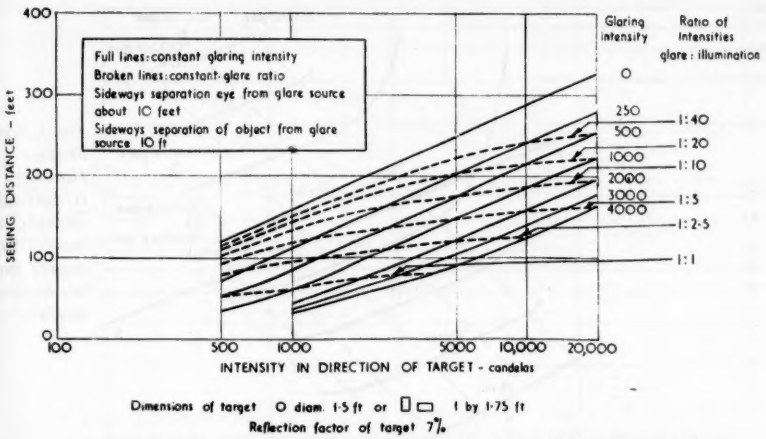

Fig. 2. Seeing distance as function of glaring and illuminating intensities.

which they first see the objects, and after a number of runs with objects in different positions a curve can be drawn which shows the seeing distance as a function of the separation between the vehicles, as in Fig. 1, which is based on results given by Roper(2). The seeing distance diminishes as the vehicles approach each other, reaches a minimum before they meet, and then rises again more rapidly as the vehicles pass and the eyes recover from the effect of the glare. It is common to attach considerable importance to the minimum distance and to attempt to increase it by improvements in design so that it shall exceed the stopping distance by a comfortable margin. The minimum seeing distance has therefore been adopted in the present work as a measure of the performance of the beam during the encounter, and the effects of lamp design, misaim and deterioration on this minimum distance have been investigated.

(3) Basic Data and Assumptions

The minimum seeing distance is obtained for an object which is almost level with the approaching vehicle at the moment of perception. Since, near a minimum, values do not change very rapidly, the seeing distance for an object just beyond the glare source is approximately equal to the minimum. Roper(3) has investigated seeing distance for this position. In his tests the glare vehicle was stationary, but such tests appear to give much the same result, as far as direct seeing is concerned, as those in which both vehicles are moving. Beams of uniform intensity were used so that the intensity directed at the object or at the driver's eyes did not change during the test run. This work has been extended at the Road Research Laboratory to those lower values of illumination and glare which are of particular importance in the design of meeting beams(4). The experimental results for a single observer, known to obtain fairly typical results in these distance measurements, have been plotted as smoothed curves in Fig. 2. The question arises whether the same seeing distances would have been obtained with more normal beams in which the illuminating and glaring intensities were not uniform and would therefore have changed during the approach of the vehicles. This has been investigated by comparing, for a number of lamps, the seeing distances actually obtained in tests and those obtained by calculation from the beam

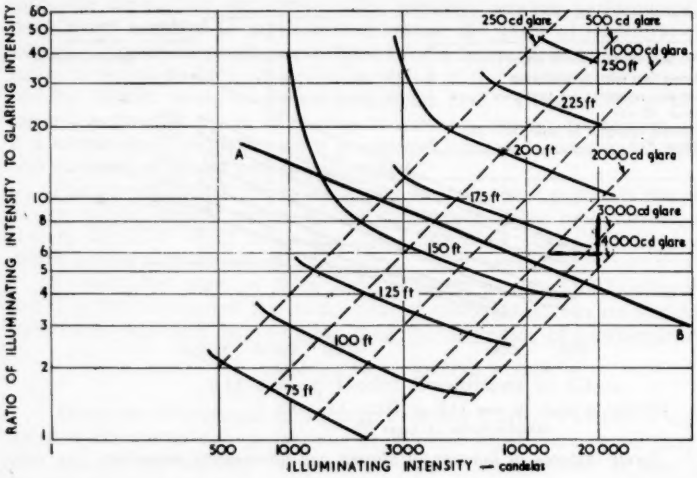

Fig. 3. Seeing distance as function of illuminating intensity and ratio of illuminating intensity to glaring intensity.

distributions(5). It was found that the agreement was reasonably good, particularly as regards the relative performances of the different lamps. It will therefore be assumed that the results in Fig. 2 apply to any distribution and that minimum seeing distances can be calculated from these curves and the beam distributions. It should be remembered, however, that these results are not completely general, and apply only to conditions similar to those of the tests in which they were obtained. Briefly, the seeing distance is that for an object about 1.5 ft. high, with a reflection factor of 7 per cent., seen on the nearside of a 20-ft. road. This standard object is a good deal lighter than the darkest clothing, which has a reflection factor of 2 per cent. or less, but is of smaller size than the average pedestrian. The broken curves in Fig. 2 show that, provided the ratio of illuminating intensity to glaring intensity is kept fixed, an increase in absolute magnitude produces only a small change in seeing distance. In Fig. 3 the same results have been plotted in a different way to show the ratio of illuminating intensity to glaring intensity required to achieve a minimum seeing distance of any desired value. These curves are more useful for the present purpose than Fig. 2.

It would be desirable to have a body of data based on a number of observers and for a range of speeds, object sizes, reflection factors, backgrounds, road widths, etc., and it is hoped that experiments will be undertaken to obtain this. It should be pointed out, however, that the main use of these calculations is to provide relative values, not absolute values, so that different designs of lamp may be compared. In this matter absolute values are not of such practical importance as might at first be supposed.

(4) Typical Features of Beam Distributions

Figs. 4, 5 and 6 show the beam distributions from one lamp(6) of a British, an American and a European meeting beam. Fig. 4 also shows the American intensity limits according to the specification of the Society of Automotive Engineers, reversed from left to right to fit the British rule of the road. The origin HS represents the horizontal direction straight ahead through the lamp; other directions are given in terms of their angular displacement to offside and nearside or up and down. Objects on a straight road 150 ft. or more ahead of the vehicle are illuminated by light of in-

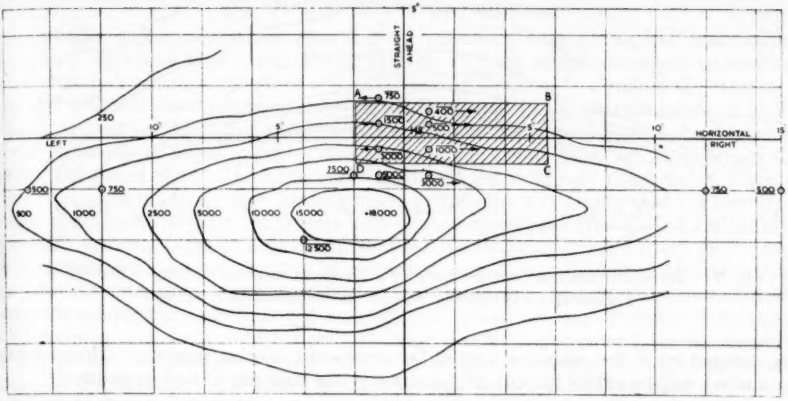

Fig. 4. Beam distribution from one lamp of a British system. Also S.A.E. recommended pratice for sealed beam lamp (reversed from left to right to suit British rule of the road). Figures to curves and reference points denote intensity in candelas; ⊙ $\overline{1000}$ means upper limit of 1000, ⊙ $\underline{1000}$ means lower limit of 1000 at point indicated by ⊙

tensities which lie within the region ABCD marked on the diagrams; the intensities causing dazzle are also found within this region. In this part of the beam the intensity increases in a downward direction. In the British or American lamp it increases towards the nearside also. In the European lamp which, unlike British or American lamps, dips vertically downwards without deflecting to the nearside, the beam has a much smaller sideways rate of change. The beam distribution in the region ABCD might be defined by stating the intensity I_0 at HS and the rate at which the intensity increases downwards and to the nearside. Unfortunately the rate of change is not constant, so that for most existing beams such a description would be somewhat complicated. To simplify the calculations which are described later it will be assumed that the intensity is increased in a constant ratio for each degree downward or to the nearside. With this assumption the isocandela lines of the beam distribution become parallel straight lines as in Fig. 7. These can be fitted fairly closely to many existing patterns in the region considered although they diverge elsewhere. The factors by which the intensity is increased in a displacement of 1 deg.

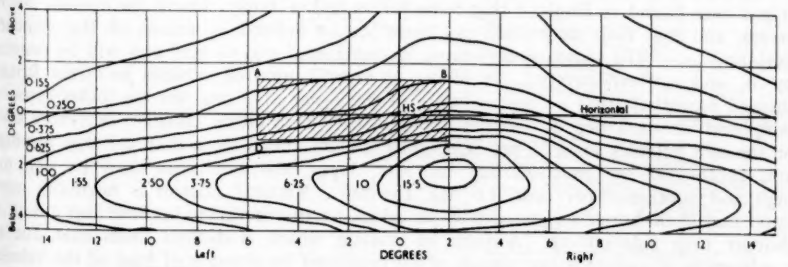

Fig. 5. Beam distribution from one lamp of an American meeting system. (See ref. (6)). Figures to curves denote intensity in thousands of candelas.

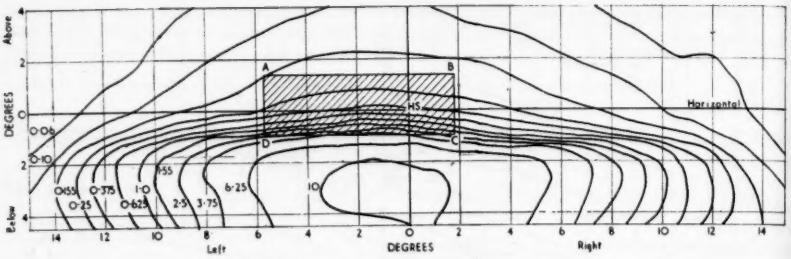

Fig. 6. Beam distribution from one lamp of a European meeting system. (See ref. (6)). Figures to curves denote intensity in thousands of candelas.

are denoted by n_1 for sideways, and n_2 for downward, displacements. The quantities n_1 and n_2 will be called the cut-off factors for side and top cut-off respectively.

Cut-off factors, as already mentioned, are not constant in the important region of typical British, European or American meeting beams. Table 1 shows typical values of n_2, and it is evident that the European lamp has much higher values of n_2, i.e., much sharper top cut-off than the others. Even in the European lamp the highest values of n_2 are not at the horizontal but a degree or so below. European lamps also differ from the others in having a lower intensity at the horizontal.

Table 1

Values of the Top Cut-off Factor n_2 Averaged over Ranges of 0.5 deg. in a Vertical Plane Straight Ahead of the Lamp.

	Below horizontal		Above horizontal	
	1.0 —0.5 deg.	0.5—0 deg.	0—0.5 deg.	0.5—1.0 deg.
British	2.5	2.4	2.2	2.7
American	3.1	4.1	2.3	1.6
European	11.9	6.1	2.2	1.5

(5) Aim of Lamps

Errors may be present in both the horizontal and the vertical aim of the beam. It has been found in England that these errors follow fairly closely the normal law of errors, and that their magnitude can therefore be defined by means of the standard deviation σ. The standard deviations for horizontal and vertical aim will be denoted by σ_1 and σ_2 respectively. A survey of several hundred vehicles in Great Britain showed recently(7) that σ_1 and σ_2 were of the order of 2 deg. for the older types of lamp and about 1 deg. for newer vehicles with flush-fitting lamps. Therefore even on the new vehicles some 25 per cent. of lamps are aimed more than 0.7 deg. too high and another 25 per cent. 0.7 deg. too low; 5 per cent. are more than 1.6 deg. too high and another 5 per cent. 1.6 deg. too low. Vertical misaim is normally more important than horizontal misaim in its effect on driver vision because top cut-off is sharper than side cut-off. A form of misaim which is distinct from that due to carelessness or neglect is the change of tilt produced by changes of load of the vehicle. This is particularly important for lorries, which may tilt upwards by as much as 3 deg. when loaded.

(6) Outline of the Calculations

Consider a pair of vehicles separated by a distance d on a road like that used in the tests from which Figs. 2 and 3 were derived. If the lamps are aimed so that one driver has just reached the point where his seeing distance is a minimum, then it is assumed that the illuminating intensity must be related to the glaring intensity in the manner shown in Fig. 3 for a seeing distance d. The probability that the intensities would have any of these suitable values can be calculated from the geometry of the layout, the beam pattern, and the probabilities of the necessary amounts of misaim. Thus it is possible to calculate for any beam pattern the probability that the minimum seeing distance for one of the drivers in a chance encounter should have the value d. It would, however, be a tedious calculation for the ordinary beam pattern and it may be simplified by adopting the sort of pattern shown in Fig. 7. When aiming is poor the relevant intensities may be derived from almost any part of the beam, but the better the aiming the more they will be restricted. Since the main purpose of the paper is to examine how far conditions may be improved by improvements in the standard of aim, it can be assumed without serious error that the whole of the beam pattern possesses the characteristics found in the restricted regions ABCD in Figs. 4, 5 and 6, i.e., that it has the simplified character of Fig. 7.

It would be possible, in the calculations, to allow for the fact that the beams encountered suffer from deterioration to varying degrees, but as this would complicate the working the only examples which have been evaluated are: (i) deteriorated lamps meeting deteriorated lamps, all of which have deteriorated to the same degree, and (ii) deteriorated lamps meeting lamps which have not deteriorated.

To carry out the calculations a given design of beam and a given standard of aiming are assumed (i.e., values of I_0, n_1, n_2, σ_1 and σ_2), and the data in Fig. 3. The fact that the curves of Fig. 3 turn upwards rapidly at the low-intensity end is ignored; the curves are assumed parallel to AB and in consequence low illuminating intensities are assumed to be more effective than they really are. It is then possible to calculate how often a minimum seeing distance falls short of any particular value d, or how often the glaring intensity or the ratio of illuminating intensity to glaring intensity exceeds any chosen value.

In the calculations on which Figs. 8 to 12 are based it is assumed that, except for deteriorated lamps, the intensity straight ahead in the horizontal is 3,000 cd. This is a typical value for the beam from a new British double-dipper system and is higher than American and much higher than European practice. Where side cut-off is not zero it is assumed that the isocandela lines are inclined at a slope of 1 in 5 as in the British lamp. It is assumed that the lamps are mounted at a height of 2.5 ft.,

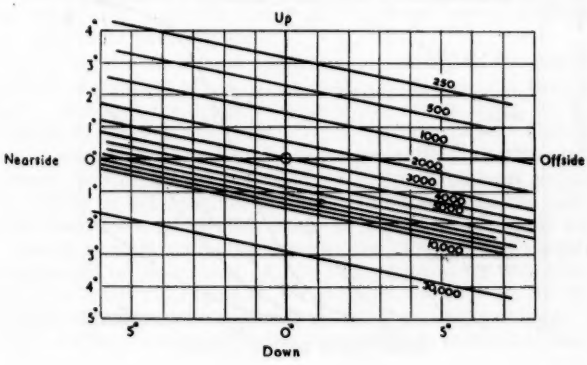

Fig. 7. Idealised beam pattern used in calculations. Actual example shown here has
$n_2 = 2.2$
$n_1 = 1.17$
$I_0 = 3{,}000$ *cd.*

and that at least 1 ft. of the target must be illuminated to the required level for it to become visible.

(7) Results of Calculations

The results of the calculations are shown in Figs. 8 to 12. It is necessary first to define the exact meaning of the probabilities shown in these figures. There is the probability that a minimum seeing distance chosen at random should be less than some distance d. There is also the probability that in an encounter chosen at random at least one driver should have a minimum seeing distance of less than d. These probabilities are different because in any encounter there are two drivers and therefore two minimum seeing distances. A large seeing distance for one driver tends to be associated with a small one for his opponent, so that the second probability based on

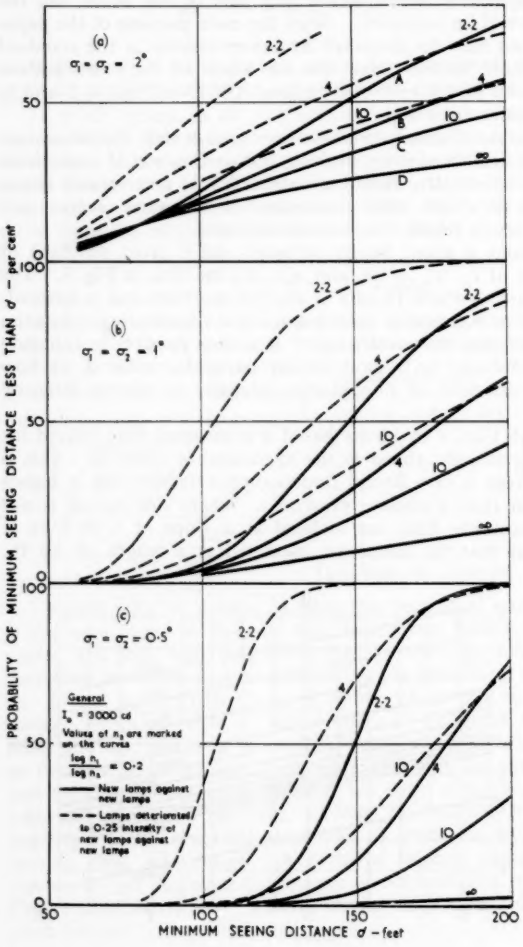

Fig. 8. Probability of minimum seeing distance as affected by misaim and deterioration.

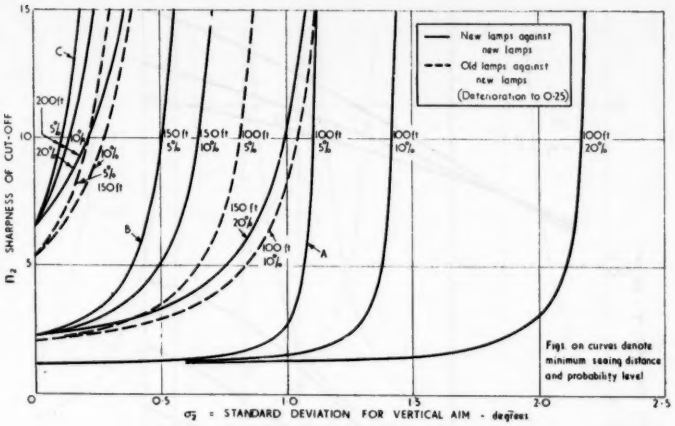

Fig. 9. Relation between cut-off and misaim for given probability of given minimum seeing distance.

the number of encounters is almost double that based on the number of seeing distances. The probabilities given in Figs. 8, 9 and 10 are of the first kind, i.e., they relate to the number of seeing distances, not the number of encounters. For example, curve A of Fig. 8(a) shows that the probability of distances less than 100 ft. is 22 per cent. In 100 encounters there are 200 seeing distances and therefore 44 of these may be expected to be less than 100 ft. It will be rare for two of these to arise from the same encounter, so that the proportion of encounters in which at least one driver has a minimum seeing distance of less than 100 ft. is about 40 per cent. When the encounters are between unlike vehicles, as in the broken curves in Fig. 8 between vehicles with deteriorated lamps and vehicles with new lamps, the probabilities refer to the seeing distances for one type of vehicle, and the probability is the same whether based on the number of seeing distances or the number of encounters. Similar remarks apply to the probability for glare intensities in Figs. 11 and 12.

(7.1) The Effect of Misaim on Seeing Distance

The full lines in Fig. 8 show the probabilities for different values of the cut-off factors and different standards of aiming. Each curve crosses the line denoting 50 per cent. probability at a distance which is the design distance for that lamp, i.e., if all lamps were of the same design and correctly aimed the minimum seeing distance would be the same for all and would have this value.

In Fig. 8(a) curve A gives results for a lamp approximating closely to the British lamp shown in Fig. 4 and for the standard of aim which exists on older cars in Britain to-day ($\sigma_1 = \sigma_2 = 2$ deg.). Although the design distance works out at about 150 ft., 22 per cent. of distances (about 40 per cent. of encounters) are less than 100 ft. Curves B, C and D show the effect of sharpening the cut-off while retaining the same horizontal forward intensity. The design performance is improved but the probability of getting seeing distances less than 100 ft. is only slightly affected, falling from 22 per cent. to 18 per cent. as n_2 is increased from 2.2 (British lamp) to 10 (maximum value for European lamps). The misaim is so large that it swamps the effect of the sharper cut-off at the low-performance end of the curves. At the high-performance end, however, the seeing distance is more often much greater, for example, than 150 or 200 ft., so that there is an improvement though not where it is presumably most important.

Figs. 8(b) and 8(c) show the results obtained when the misaim is reduced to one-

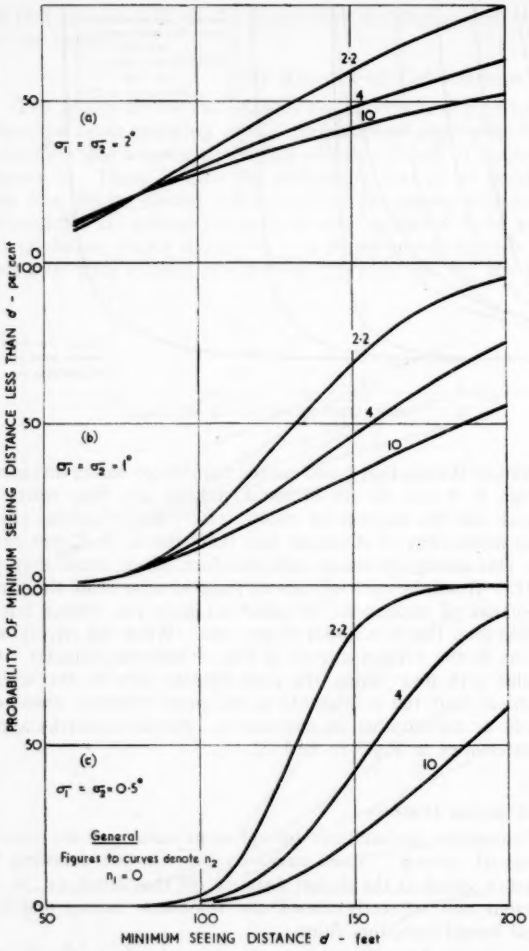

Fig. 10. Probability of minimum seeing distance for lamps without side cut-off.

half and then to one-quarter of that assumed in Fig. 8(a). Design performance is not affected, i.e., the curves still cross the 50 per cent. probability line at the same values of d, but the probability of distances less than the design value is reduced, and in this example, for instance, the probability of distances less than 100 ft. is very greatly reduced. If the standard deviation of aim could be reduced as in Fig. 8(c) to 0.5 deg., seeing distances less than 120 ft. would not occur in more than 5 per cent. of the total, i.e., in fewer than 10 per cent. of encounters with the present British lamp. A further improvement would be possible if there were some sharpening of the cut-off.

Another way of setting out the results, and one which brings out more clearly the connection between design and standards of aiming, is shown in Fig. 9. This shows what values of n_2 and σ_2 are required in order that the probability of distances of 100,

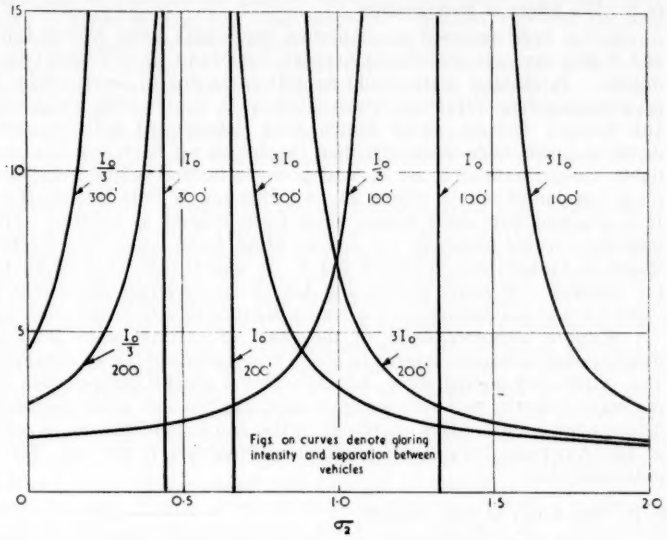

Fig. 11. Relation between cut-off and misaim for 5 per cent. probability of glaring intensity exceeding $\frac{I_0}{3}$, I_0 and $3I_0$.

150 or 200 ft. should be kept at some low figure. For example, if seeing distances less than 100 ft. are to form 5 per cent. or less of the total, then n_2 and σ_2 must be given by points on or to the left of curve A. If σ_2 is 2 deg. this is clearly impossible. If σ_2 just exceeds 1.1 deg. it becomes possible, but a very sharp cut-off (n_2 greater than 8) is required. If σ_2 is less than 1 deg. it is possible to obtain the low probability with values of n_2 as low as that for the British lamp or even lower.

Curve B for 150 ft. is similar but more demanding both as regards aim and sharpness of cut-off. Curve C for 200 ft. calls for a still sharper cut-off and a standard of aiming so high that in order to attain it lamps on lorries would certainly have to be adjusted for changes of load, and it might even be necessary to readjust the aim on cars according to the number of passengers in the back seat. The addition of one passenger tilts the average British car about 0.2 deg.

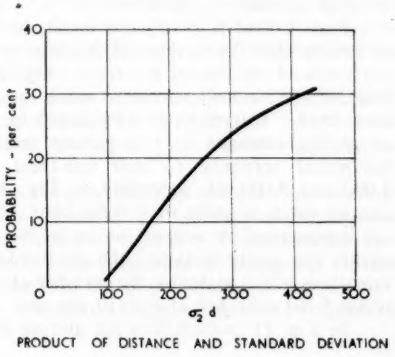

Fig. 12. Probability of glaring intensity exceeding the forward intensity in the horizontal I_0.

(7·2) The Effect of Deterioration

It has been assumed in calculating the results given by the full lines in Figs. 8 and 9 that the only differences between the beams on different vehicles were due to misaim. In practice there would be differences due to deterioration and to the effect of manufacturing tolerances which allow quite considerable variations between beam and beam. Drivers whose lamps have deteriorated will experience short seeing distances much more frequently than the drivers we have just been considering, whose lights, though misaimed, are at least giving a normal output. Calculations have been made for lamps whose output in any direction is only one-quarter of the normal. It is assumed that these lamps suffer from misaim as before. The probability of minimum seeing distances for drivers using these lamps but meeting new lamps is shown by broken lines in Figs. 8 and 9. It is clear that for a seeing distance of 100 ft. the demands are fairly severe, and for 150 ft. wellnigh impossible, being somewhat similar to the requirements for a seeing distance of 200 ft. with new lamps.

A more elaborate study of the effect of mixing beams with various levels of deterioration is clearly required to give a true picture of the importance of deterioration. The results just quoted show, however, that a general deterioration to one-quarter of the initial intensity will very seriously handicap the user when meeting beams from undeteriorated lamps. It is interesting in this connection that the recommended standard of the American Society of Automotive Engineers is not less than one-half of the initial intensity.

(7·3) The Effect of Side Cut-Off

Fig. 10 gives the probabilities for beams which differ from those of Fig. 8 (full lines) only in having no side cut-off. The curves show that the side cut-off adopted in the idealised beam (very similar to that of the British lamp in Fig. 4) increases the seeing distance by about 20 ft. For sharper side cut-off (isocandela lines sloping down more sharply) the increase would have been larger. The improvement thus produced in the visibility of objects on the nearside of the road may, however, be accompanied by a deterioration for objects more to the offside. If side cut-off is used it should not extend much below the horizontal or the visibility on the offside of the road will be seriously reduced.

(7·4) Glaring Intensities

Although the discomfort caused by a headlight does not depend simply on the intensity of the beam, the intensity is probably the most important factor. When the design of the meeting beam is governed by regulation it is usual to have an upper limit to the intensity which can be directed into the eyes of approaching drivers. It is of interest, therefore, to find the effects of misaim and sharpness of cut-off on the intensities actually encountered.

Figs. 11 and 12 give some results for the simplified beam of Fig. 7. It is assumed as before that the horizontal intensity is maintained at the fixed value I_0 while the sharpness of the cut-off is varied. Fig. 11 is similar to Fig. 9 and shows the relationship between cut-off and aim which is required to keep the probabilities at the 5 per cent. level. Curves have to be drawn for each separation of the vehicles and each level of glaring intensity. The glaring intensities chosen for Figs. 11 and 12 are the horizontal intensity I_0 and one-third and three times this intensity, i.e., 1,000. 3,000 and 9,000 cd. according to Fig. 7. The glaring intensity will not exceed the chosen value in more than 5 per cent. of the total, provided that the aim and cut-off are represented by a point on or to the left of the appropriate curve. As with the curves for seeing distance, the probabilities are calculated on the number of glaring intensities which is double the number of encounters, and the probability for encounters is not 5 per cent. but almost 10 per cent.

In Fig. 11 probabilities for glaring intensities exceeding I_0 are independent of the

cut-off and for this special example the general relationship between probability and standard of aiming is given in Fig. 12. The probability remains constant for this particular value of the glaring intensity because it is being assumed that I_0 remains constant while the cut-off is changed. The misaim required to bring this intensity to the driver's eyes remains constant and so, therefore, does the probability. Other assumptions might be made; in some countries, the United States for example, even intensities below the horizontal are limited by legislation or agreement. Figs. 11 and 12 may be used in investigating such conditions provided I_0 is then regarded as dependent on the cut-off factor n_2.

It is an important question whether changes in cut-off necessary to achieve large seeing distances can be made without running into serious trouble from high glaring intensities. An improvement in the standard of aiming makes it less likely that high glaring intensities will be encountered; the effect of sharpening the cut-off is more complicated. If the cut-off is made sharper, high intensities become more probable and low intensities less probable; the intensity for which the probability remains unchanged is, as already shown, the intensity which remains fixed while the cut-off is varied, i.e., in our calculations the horizontal intensity I_0. A comparison of Figs. 9 and 11 shows that to keep down intensities exceeding $I_0/3$ (1,000 cd.) to a probability of 5 per cent. for a distance of 200 ft. requires standards of aiming and sharpness of cut-off very similar to those required to achieve seeing distances of the same order with the same probability level. There is, in fact, a correspondence between the two diagrams which may be expressed as follows: if the cut-off and standard of aiming give probability p for seeing distances less than d, then when the vehicles are separated by a distance d the probability for glaring intensities exceeding kI_0 is also less than p. The factor k is a function of the separation and is given in the following table; for distances greater than 150 ft. it is less than 0.3.

d ft.	100	150	200	300	400
k	0.7	0.3	0.125	0.02	0.004

It follows from this that if, as a result of sharpening the cut-off and improving the aim, the performance of beams is improved relative to seeing distance, it will also be improved relative to glaring intensities. This suggests that apart from intermittent dazzle due to the pitching motion of vehicles, comfort will look after itself if visibility is dealt with. It is the intermittent dazzle therefore which probably sets an ultimate limit to the sharpness of cut-off that can be used.

(8) Conclusions

The effectiveness of a meeting beam should be judged not by its performance when correctly aimed and in perfect condition, but by the performances which will be given by such beams in actual use when subject to the inevitable effects of misaim and deterioration. A method of evaluating this overall performance can be based on the minimum seeing distance and the glaring intensity.

Judged in this way the performance of any given design depends on the standard of aiming and on the degree of deterioration which is to be tolerated. Curves are available from which the effects of the various factors and the connections between them may be seen.

An attempt to increase the minimum direct seeing distance at most encounters to much over 150 ft. for the standard test layout demands an accuracy of aiming and sharpness of cut-off which it will be difficult to achieve, especially if deterioration to a small fraction of initial intensities is tolerated. The prospects of designing a beam which will effect any considerable improvement are therefore small.

The sharp cut-off, coupled with a high standard of aiming which is required if

improved seeing distances are to be attained, is not likely to give rise to high glaring intensities, except for intermittent glare due to the pitching motion of the vehicle, or at places, such as hilltops, where the slope of the road is not constant. If it may be assumed that standards of aiming can be greatly improved, then it is the intermittent dazzle due to the pitching motion which probably sets a limit to the sharpness of cut-off which may be used.

Acknowledgments

This paper was prepared at the Road Research Laboratory of the Department of Scientific and Industrial Research, and is published by permission of the Director of Road Research.

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(2) Roper, V., and Scott, K. D., Trans. Illum. Eng. Soc. (N.Y.), **34**, 1073 (1939).
(3) Roper, V. J., and Howard, E. A., Trans. Illum. Eng. Soc. (N.Y.), **33**, 417 (1938).
(4) Jehu, V. J. "A method of comparing the performance of vehicle meeting beams." Road Research Laboratory Note No. RN/1597/VJJ, July, 1951. (Unpublished.)
(5) Jehu, V. J. "A comparison of four vehicle meeting beams in common use." Road Research Laboratory Note No. RN/1598/VJJ, July, 1951. (Unpublished.)
(6) Nederlandse Stichting voor Verlichtingskunde. International visibility tests with motor-car lighting carried out at Zandvoort (Holland) in October, 1949, in accordance with the resolution of the Committee 23b of the Commission Internationale de l'Eclairage at the meeting held in Paris in 1948.
(7) Jehu, V. J. "A survey of vehicle headlamps and passlamps, May, 1952." Road Research Laboratory Note No. RN/1836/VJJ, September, 1952. (Unpublished.)

Additions to the List of Members

The following applicants have been duly elected by the Council to membership in the Society and their names have been added to the list of members:—

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Fellowship

The Council has accepted the following application for Fellowship of the Society:—
Mr. C. C. Smith.

Register of Lighting Engineers

The Council has accepted the following application for inclusion on the Register of Lighting Engineers:—

Mr. M. S. Barton.

Classification of Diffusing Materials*

(1) Introduction

There are many different kinds of materials used for diffusing light, including, for example, opal glass, ground glass, patterned glass, opal and patterned plastics, textiles and papers, and this paper is an attempt to classify them according to the optical means by which the diffusion is produced.

The subject of opal glass has been fully studied by the Commission Internationale de l'Eclairage (C.I.E.) through its Committee 22A and, in 1948, the C.I.E. resolved[1] to extend its studies to other types of diffusing materials, and to methods of classification. Attention was drawn to a paper on terminology by M. Prokop[2] which included an elaborate and comprehensive analysis of the physical, chemical and technical properties of glass but which did not seem directly suitable for a general classification of diffusing materials. The British National Illumination Committee accordingly prepared a report on a method of classification and this was adopted at the 1951 meeting of the C.I.E.[3]. Unfortunately, however, this report was not included in the recently published Proceedings of the 1951 C.I.E., and accordingly it is given in this paper, together with some explanatory amplification.

The process of diffusion may be described for the purpose of this paper as a random redirection of light, within a wide or restricted solid angle, by numerous elements of negligible size which scatter, reflect or refract the rays falling upon them. This definition covers both the angular spreading effect caused by opalescent or stippled materials receiving a narrow beam of light, and the apparent broadening of a source of light when a diffusing material is placed between the source and the observer. It does not include the effects of inter-reflexion in a room or the effects of a large-area light source. In many glossaries, the word "diffuse" is the antonym of "direct," implying that diffused light lacks the precisely definable character of directed light. Most materials are preferentially diffusing and yield a luminance or intensity which shows one or more maximum values in particular directions; materials which are fully diffusing show a luminance which is substantially independent of direction.

Some of the types of diffusing material mentioned below are classified in terms of their "diffusing power" and of their Ryde and Cooper constants, these properties having been adopted by the C.I.E. for international use[4].

Diffusing Power is defined photometrically by the relation :—

$$\text{Diffusing Power} = \frac{L_{20}+L_{70}}{2\times L_5}$$

where L is the luminance of the material when illuminated normally by a narrow beam of light and when observed from angles of 20 deg., 70 deg. and 5 deg. respectively. The C.I.E. reports on Diffusing Power use the symbol B for brightness instead of L for luminance.

The Ryde and Cooper constants[5] relate to material with embedded diffusing particles (opal materials), the principal constants being: μ which is a measure of the absorption properties, q which is a measure of the scattering properties, and NB which is dependent on the number and size of the embedded particles.

The direct transmission factor of the material is given by

$$\text{Direct transmission factor} = e^{-qX}$$

where q is the total scattering coefficient and X is the thickness in centimetres.

The relations governing the constant NB are complex but it may be noted that a

* This paper is based on a report submitted by Great Britain at the Stockholm meeting of the International Commission on Illumination in 1951.

high value of the product NBX corresponds to a dense opal, whilst a low value corresponds to a translucent material of low diffusing power.

It has been shown[6] that the characteristics of a lighting fitting, with an opal glass or acrylic plastic diffuser, may be calculated from these constants.

Other terms in this paper are used in the sense of the British Standard Glossary 233: 1953—"Terms used in Illumination and Photometry."

(2) Classification

The principal classes of diffusing materials are:—

(I) Materials with embedded diffusing particles.
(II) Surface-treated materials.
(III) Materials with moulded or patterned surfaces.
(IV) Textile, paper and other diffusers.

The first three classes are subdivided as set out below and the fourth class includes materials of a fibrous nature which have not been classified in detail.

(I) Materials with Embedded Diffusing Particles

These materials have a very large number of particles distributed through the whole or part of their thickness. They may be divided roughly into two classes according to whether they contain (A) very small (microscopic) or (B) relatively large particles. In normal thicknesses, the materials of Class A are practically fully or uniformly diffusing while those of Class B are only partially diffusing. When the thickness of materials in either class is reduced or the concentration of the particles is relatively low, some direct transmission is shown.

(A) *Fully Diffusing Materials*

These materials have properties closely approaching those of a uniform diffuser when in practicable thicknesses, and are characterised by a relatively high diffusing power and negligible direct transmission. They may be white or coloured. The diffusing particles may be distributed through the whole thickness (Examples: Solid opal glass, pot opal, some opal acrylic plastics), or through one or more layers (Examples: Cased opal, flashed pot opal, 2-ply, 3-ply opal glasses, laminated opal plastics). For materials of this class, the scattering is produced by a relatively large number of very small particles and it is generally found that, in terms of the Ryde and Cooper constants, NBX is over 1.0 and qX is over 12.

(B) *Partially Diffusing Materials or Mixed Diffusers*

These materials show preferential or mixed diffusion when in practicable thicknesses and they may be white or coloured. They are of two main types:—

(i) Opalescent materials, having relatively high diffusing power and appreciable direct transmission.

When viewed with small source of "white" light behind them, non-coloured materials of this class give a characteristic appearance in that the source appears of an orange or reddish colour and the rest of the sheet or globe appears a somewhat bluish white owing to the more strongly scattered blue light. In this sub-class it is generally found that qX is under 10.

An example of this class is a thin opal glass.

(ii) Translucent materials, having relatively low diffusing power.

Materials of this class, when viewed in front of a small source of light do not appreciably change its colour appearance, unless the material itself is coloured. In this sub-class, the scattering is produced by a relatively small number of much larger particles than those in A and B (i) above, and it is generally found that the value of NBX is under 1.0. These materials exhibit preferential diffusion.

Materials which are thick enough to obscure the filament of a lamp may have

values of qX over 12 and those which are thin enough to have an appreciable direct transmission may have values of qX under 10.

Typical materials are known by several names, such as Moonstone, Diffusalyte, Lunalyte, Perspex 030.

(II) Surface-Treated Materials

(A) Chemically Treated Surfaces

These materials are clear, white or coloured glass or plastics of which one or both surfaces have been chemically etched to give a diffusing effect. (Examples: Acid treated glass, stipple etched glass, coarse etch, dense etch, white etch, embossed etched glass.)

(B) Abrasive Treated Surfaces

These materials are clear, white or coloured glass or plastics of which one or both surfaces has been abraded to give a diffusing effect. They are of two types: (i) Abrasive blasted surfaces such as sandblast, emery blast, shot blast; (ii) Abrasive ground surfaces such as ground glass, frosted glass.

(C) Coated Materials

Diffusers composed of a transparent medium which has received a coating by painting, spraying or similar process. These may be similar to the flashed or laminated materials mentioned in Class I(A) above. (Example: Materials with white or coloured sprayed lacquered surfaces.)

(III) Materials with Moulded Surfaces

These materials are clear, white or coloured glass or plastics with a moulded or figured pattern formed on one or both surfaces to give a diffusing effect. Many materials of this class combine two or more of the types of diffusion described below.

(A) Random Diffusers

These materials have the property of diffusing a pencil of light in random directions within a cone of small or large angle, the axis of the cone being substantially collinear with that of the incident pencil of light. (Examples: Rough cast, stippled glass, arctic glass, pinhead glass, muranese glass, pinhead acrylic plastic.)

(B) Anisotropic Diffusers

These materials show an asymmetric diffusion greater in one plane than in one at right angles to it, or displaced from the direction of incidence. They are of two types:—

(i) Prismatic diffusers.

These materials bear a designed prismatic pattern which redirects an incident pencil of light into a preferred direction usually with a small degree of random diffusion about that direction. (Example: Prismatic window glass.)

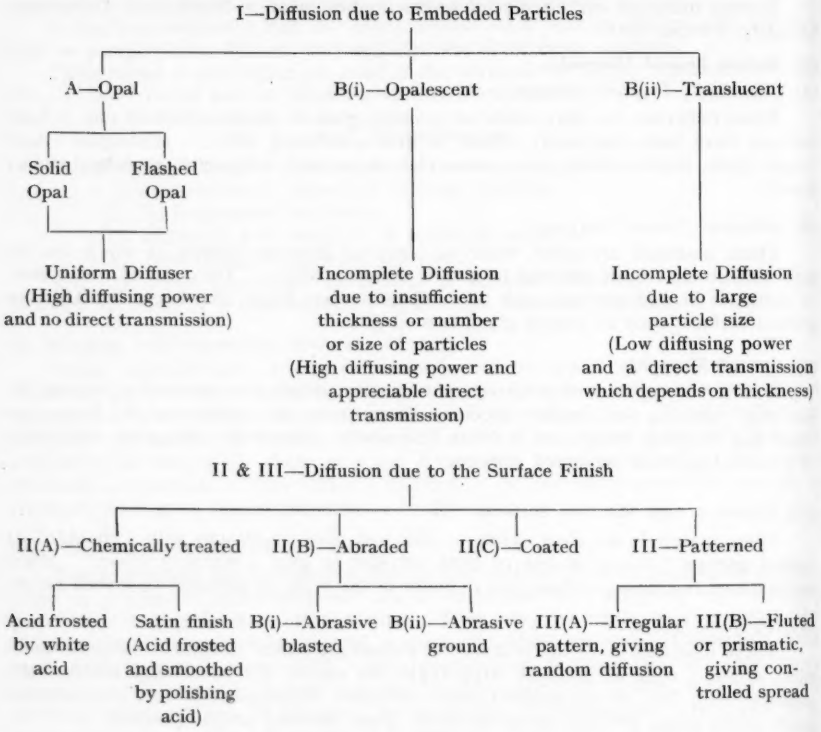
(ii) Spreading diffusers.

These materials bear a pattern of parallel flutes which spread the light in one plane, within a fan of small or large angle, the centre of the fan being substantially collinear with the axis of the incident pencil of light. (Examples: Fluted glass, reeded glass, luminating glass, ribbed glass, fluted or reeded plastics.)

(IV) Textile, Paper and Other Diffusers

Paper, parchment, vellum, plastics-treated fabrics and other materials having properties similar to those itemised above, such as materials used for decorative shades, back-projection screens, etc. Most of these materials exhibit preferential diffusion.

(3) Diagrammatic Representation of the Principal Types


I—Diffusion due to Embedded Particles
A—Opal
B(i)—Opalescent
B(ii)—Translucent
Solid Opal
Flashed Opal
Uniform Diffuser (High diffusing power and no direct transmission)
Incomplete Diffusion due to insufficient thickness or number or size of particles (High diffusing power and appreciable direct transmission)
Incomplete Diffusion due to large particle size (Low diffusing power and a direct transmission which depends on thickness)
II & III—Diffusion due to the Surface Finish
II(A)—Chemically treated
II(B)—Abraded
II(C)—Coated
III—Patterned
Acid frosted by white acid
Satin finish (Acid frosted and smoothed by polishing acid)
B(i)—Abrasive blasted
B(ii)—Abrasive ground
III(A)—Irregular pattern, giving random diffusion
III(B)—Fluted or prismatic, giving controlled spread

(4) Acknowledgment

This report was prepared by Mr. J. G. Holmes for the B.S.I. sub-committee on Diffusing Materials, under the chairmanship of Dr. S. English, acting for the National Illumination Committee.

References

(1) The text of the decision is "It is recommended that the Secretariat Committee should study all methods for the classification of diffusing materials."
It was also recommended that "National Committees should study the diffusion produced by moulded glasses . . . and . . . the best method of defining their diffusing properties."

(2) M. Prokop, "Classification and nomenclature of glass." Published (1939) by Elektrotechniky svaz ceskoslovensky, Prague (in Czech).

(3) The text of the decision is "It is recommended that the British memorandum 'The Classification of Types of Diffusing Materials' be printed as an addendum to the Secretariat Report."

(4) Proc. C.I.E. (1935).

(5) Ryde, J. W., and Cooper, B. S., Proc. Roy. Soc., A, **131**, 464 (1931). J. S. G. T. **16**, 408 (1932), Illum. Eng. (Lond.) 33, (Feb., 1933).

(6) Holmes, J. G., Trans. I.E.S. (Lond.), **3**, 87 (1938).
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The Design of the Visual Field*

Summary

This report was prepared for the National Illumination Committee of Great Britain by its Sub-Committee on the Principles of Lighting. It reviews the aims, the mechanism and the calculation of interior lighting. Recently the conception of interior lighting has progressed beyond the provision of illumination on a working plane to include decoration, brightness distributions, discomfort, emphasis, modelling and other matters. There has, however, not been hitherto a statement of the problem as a whole, so that the several aspects can be reviewed in their proper relationship; the Lighting Principles Sub-Committee therefore undertook the task of preparing such a statement, which is published by the authority of the National Illumination Committee.

The report is in three parts. Part I reviews the aims of good lighting, and indicates the considerations which should weigh with the designer in specifying a brightness distribution. Part II discusses the mechanism of interior lighting, reviewing the phenomena of adaptation, the necessary amount of light, questions of emphasis, contrast, comfort, modelling, and colour and decoration. Part III discusses the formation of the brightness pattern and the methods of predetermining it. The state of knowledge in the various sections and the possible direction of future work is indicated.

Introduction

In the revised programme of work for the C.I.E. two subjects appear, the study of which in Great Britain was entrusted to a single committee. The subjects were the Predetermination of Illumination and Brightness, and the Estimation of Comfort in Lighting.

It was clear to the committee that these two subjects were only two pieces from a large puzzle, and that they could not be properly studied alone. For some years the lighting of interiors has been recognised as extending far beyond the provision of light on a working plane; its aim is becoming the design of the visual field, including architecture, decoration, furnishing, emphasis, modelling, comfort and efficiency, not yet in any co-ordinated way, but one day to be conceived and designed as a whole. A review of the whole was needed to appreciate the parts. The committee therefore co-opted members who could bring specialised knowledge of architecture and interior lighting as well as of the two original matters, and widened their scope to that of a study committee covering the whole field of Lighting Principles. Their first act was to draw up a short memorandum indicating the scope of the problem, the headings of which were then divided among three working parties who made more detailed reports. These have been combined into the present report, which surveys the present state of knowledge and indicates directions in which future work might go. It does not claim to solve problems, but only to review and relate them. It is published by the authority of the National Illumination Committee of Great Britain.

Part I: The Aims of Good Lighting

The aim of good lighting is to reveal adequately all objects in an interior, with appropriate emphasis and pleasing appearance, without discomfort to users and in such a way that they can easily perform their visual tasks. This involves providing the right amount of light in the right places from the right directions, so as to achieve the right brightnesses of source, task and the whole of the visual field. Insufficient or badly distributed light or too much light in the wrong places may lead to poor seeing or to discomfort.

Vision is facilitated if the object of regard is distinguished clearly from its surroundings, either by being brighter, or more contrasty, or more colourful or all three.

* A report prepared for the National Illumination Committee of Great Britain by the Sub-Committee on Lighting Principles. Manuscript received July 15, 1953.

Good lighting, therefore, singles out the main points of visual interest and places them in an unobtrusive and unconfusing setting, neither so bright and colourful that the attention is attracted away from the centre of attraction nor so dark that the attention is forced too aggressively on to it. Good lighting provides moderately bright and unobtrusive backgrounds to give the eyes a suitable state of adaptation. Vision is facilitated if the form and texture of the object of regard is presented in an easily recognisable way; and good lighting, therefore, provides light from such directions that an appropriate pattern of light and shade contained within the objects of regard is formed.

(1.1) Efficiency and Comfort

Lighting may be designed with visual efficiency or with visual comfort as its principal aim, according as the users will be engaged in critical or in casual seeing. The two aims are not necessarily in conflict; for example, critical work will demand comfort as one requirement. But lighting designed with comfort as a principal aim would not necessarily be suitable for critical seeing nor promote the highest visual efficiency.

(1.1.1) *Visual Efficiency*

Visual efficiency may be loosely defined as the effectiveness with which the eyes can obtain critical relevant information from the scene presented to them. The demands for visual efficiency vary greatly according to the task, and how much information is there to be obtained; for example, if the user is engaged in a visually simple and crude task, such as shovelling coal, his possible visual demands are easily met, and further improvements in his conditions will not usefully improve his visual efficiency in that situation. If he is engaged in jewel mounting or fine instrument work, the highest possible visual performance is needed and every artifice of design can be valuable in promoting it.

Some of the factors governing visual efficiency are:—

(i) *The Amount of Light*

Visual efficiency generally increases as the general level of brightness increases, up to a maximum depending on the task and the detailed study which it demands. At very high levels of brightness visual efficiency may diminish.

(ii) *The Size of the Critical Details of the Task*

The larger the detail the higher the visual efficiency under given conditions and the more easily will maximum efficiency be attained.

(iii) *The Contrast of the Critical Details Contained within the Task*

The greater this contrast, within limits, the higher the visual efficiency up to a level depending on the conditions.

(iv) *The Relation between the Brightnesses of the Task Area and that of its Surround*

There is good reason to believe that by analogy with visual acuity, visual efficiency is greatest when the task is somewhat brighter than its surroundings and that visual efficiency is reduced if the task is darker than its surroundings.

(v) *The Relation between the Pattern and Texture of the Task Area and that of its Surround*

If the texture of the task is similar to that of its background, visual efficiency may be low because of the difficulty of distinguishing or recognising the task.

(vi) *The Relation between the Colours of the Task Area and of its Surround*

A moderate colour contrast can increase visual efficiency, and in certain circumstances strong colour contrast may reduce efficiency.

(1.1.2) *Visual Comfort*

Visual comfort implies the sense of pleasure, well-being and satisfaction evoked by the whole visual scene. The pleasure induced by the specific content of the scene is not included here, but only the satisfaction of being able to appreciate the content in an unhampered and stimulating manner. The kind of visual comfort and the way it is achieved will differ in a restaurant, a church, an office or a dance hall. Although visual comfort requires the elimination of causes of discomfort it is more than the mere absence of discomfort, which may be vague and flat, and it may involve stimulating lighting to provide centres of interest.

Some of the factors affecting visual comfort are:—

(i) *The Gradation of Brightness and Contrast in the Field of View*

Strong and sharply defined contrasts, though sometimes stimulating, may cause discomfort if excessive. Graded contrasts may cause less discomfort for the same overall brightness range.

(ii) *The Presence or Absence of Bright Sources of Light*

Large bright sources may cause glare discomfort, but small bright sources may lend sparkle and interest without discomfort.

(iii) *The Presence or Absence of Centres of Attraction*

If there is a task which demands mental concentration, or if the interior has an intended focus of attention, comfort is aided by focal lighting which draws the eye naturally to it. A very marked "phototropic" effect (see Section 2.3.1) may be uncomfortable, and the absence of any phototropic effect may be soporific. A conflict between the intended and phototropic centres of attraction may be disturbing and fatiguing.

(iv) *The Provision of Visual Rest Centres*

Visual comfort in some situations may be aided by the provision of visual rest centres. These are discussed in more detail in Section 1.1.3 below.

(v) *The Directional Character of the Lighting*

Lighting with little directional character may cause no discomfort, but generally lacks interest and is boring. A good design will make conscious use of directional effects to reveal coherently the shapes of the interior and its contents.

(vi) *The Nature of the Colour Pattern*

Some colour contrasts can give a phototropic effect without causing discomfort, whilst others may be acutely irritating. A good design of the visual field will make full use of colour in providing an environment, stimulating or restful, appropriate to its purpose.

(1.1.3) *Visual Rest Centres*

These are areas not having a strong phototropic effect, but to which the eye can gravitate if it has no specific task to undertake. They may be relatively dark so that there is no conspicuous pattern to be perceived by the eye, or they may be light and of low contrast provided that the pattern produced is inconspicuous and offers an easy visual occupation in its interpretation. The purpose of the visual rest centres is to allow the gaze to be relaxed and to avoid any strong visual and mental stimulus.

(1.2) Specification of the Visual Field

Consideration of the principles set out briefly and qualitatively above will lead the designer to a conception of the kind of visual field that he wishes to produce, having balanced the claims of efficiency, comfort and interest. There is an aesthetic and artistic creation in his mind; in order to realise it he must be able to express it in figures, and to design and locate the lighting equipment which will produce the effect, often without being able to experiment because the building is not yet in existence. He

must thus understand quantitatively the physical and visual processes at work, and must be able to predetermine them. These two aspects of the problem are discussed in the two following parts.

Part II: The Mechanism of Interior Lighting

An interior is lighted by releasing light within it, either by daylight from outside, or by lamps usually within it and usually associated with lighting equipment of some kind. The following processes and consequent results then occur:—

(i) *Interreflection.*—The light from the lamps, redistributed by the lighting equipment, is interreflected within the room by all the surfaces of every part, so that. from any point within it, the surface of every part of the room and its contents takes up a brightness and a pattern of brightness is formed.

(ii) *Colour and Decoration.*—The brightness pattern is largely determined by the scheme of decoration of the interior, and is thus interrelated with the scheme of colour and colour harmony.

(iii) *Brightness Pattern.*—The brightness pattern so formed does two things: (a) it illuminates every point in the interior, resulting in a flow of light to that point varying in amount with the direction from which it comes; and (b) it provides the means whereby users of the room perceive the room itself and the objects within it.

(iv) *Adaptation of the Eyes.*—As a result of the brightness pattern the eyes of the users are adapted to a brightness level, which may vary according to their direction of view.

(v) *Brightness of Task.*—The brightness pattern of the interior as seen from the object of regard determines the illumination of, and hence the brightness of, that object, both absolutely and relatively to the rest of the brightness pattern and to the adaptation level of the eyes. Thus it determines the adequacy with which the task can be seen.

(vi) *Glare and Comfort.*—The brightness pattern determines whether users will experience glare, discomfort or distraction.

(vii) *Concentration of Attention.*—The brightness pattern also determines the concentration of attention of users; it can be organised so as to enhance effects which the architect is seeking or it may conflict with the wishes of the architect or the user and constitute a distraction.

(viii) *Revealing of Architecture and Objects.*—The architecture of the interior and the forms of solid objects are revealed by a complex pattern of "light and shade" which they present. Since the field of brightness which such objects can see is not uniform, the illumination (and therefore the brightness) of their surfaces varies with orientation, in a more or less regular way, and this gives rise to a modelling effect; moreover shadows are cast by one portion upon another. These effects are of the greatest importance in the appearance of the interior.

These headings indicate consecutively the inevitable processes at work in a lighted interior. The complete design of the visual field in an interior will not be possible unless for each of them, and perhaps for some others, we can measure, prescribe, predict and provide desirable conditions; and evidently they are all interrelated.

It is convenient to discuss the various factors in a different order from that used above. The formation of the brightness pattern is part of the subject of Part III; its effects are discussed in this Part.

(2.1) Adaptation

The process of adaptation, perhaps the most obvious characteristic of vision, has not been sufficiently taken into account in illuminating engineering. By this

mechanism the visual system adjusts its sensitivity automatically so that the sensations received from the visual field lie in as convenient a range as possible. Though the mechanism of adaptation has been thoroughly studied, its implications have not been much applied in practice, though they are evidently far-reaching.

The most important effect is that the apparent effect of the brightness of any component of the visual field is indicated not only by its absolute value, but rather by its relation to "the adaptation level," using that term loosely for the moment. For example, a given absolute level of luminance appears bright if its surroundings are of lower luminance, and appears dark in surroundings of higher luminance. The effects of adaptation are usually appreciated in extreme cases, but they are fundamental to all lighting. The absolute amount of light prescribed as illumination for a given task, as indicated in Lighting Codes (see Section 2.2) can really only be so prescribed because of a simplification, based upon the conditions in which that task is usually performed; it is valid only if certain accompanying rules of lighting are complied with. Absolute levels are usually far less important than relative levels of brightness, though in some respects absolute values may be significant. In this connection there are valuable lessons to be learned from the practice of expressing interior daylight as a ratio, which has advantages over an absolute measure besides the original advantage of constancy. This matter has been and is being studied in some detail, and there may result from it a further understanding of interior artificial lighting.

The capacity of the visual process for adaptation is not, however, unlimited, and the range of luminance which can be appreciated usefully and comfortably at one time depends upon the adaptation level. At high levels, the upper end is restricted, and luminances much above the adaptation level become uncomfortable. At lower levels, the lower end is restricted, and sensations from luminances much below the adaptation level become inadequate. For many years, when only low levels were practicable, we have been preoccupied with this lower end, and very properly tried to increase all brightnesses in the field sufficiently to give adequate sensation at the lower brightnesses. Now that enough light for this aim can be easily provided, the amount provided has become less important; but the other limit has sometimes been reached, in which discomfort has been experienced at the upper end of the brightness range. The basic cause of discomfort is a range of brightness which is excessive for the adaptation level concerned.

There are several distinct processes involved in adaptation, some general and some local, operating at different rates. Complete adaptation to darkness after exposure to a high brightness such as daylight requires a long time, but adaptation to the much smaller changes in moving the direction of vision from one part of the field of view in an interior to another, takes place much more quickly. Probably the brightness of the immediate surroundings of the object of regard has a predominant effect in determining the adaptation level; probably also the adaptation is not the same over the whole retina. It is probably an over-simplification to speak of "the" adaptation level in an interior; the level will change with the direction of view and perhaps with the degree of attention given to objects in view. Nevertheless, some simplification will be necessary; there is need for much more work on adaptation in practical situations to ascertain what happens and how approximations can be safely made.

It has been argued that visual sensations can never be numerically expressed. It is an axiom almost universally agreed that sensations cannot be measured, but nevertheless some numerical expression is clearly needed and appears to be possible, even though it may be formally unjustifiable. Work by Hopkinson some years ago provided a tentative scale of apparent brightness, and this scale has been found to be valuable in appraising brightness patterns, though its validity is by no means established. He has recently confirmed the results for the conditions to which they apply, but his work has indicated further problems and the urgent need for further

investigation. This approach may provide a most valuable tool for the lighting engineer.

(2.2) The Amount of Light for the Task

The amount of light which is necessary if a visual task is to be done well and in comfort depends upon the adaptation level and the relation of the brightness of the task to that level; it also depends upon the size of the critical detail in the things which have to be discerned, the internal contrasts of these details and their contrasts with their background.

In most interiors in which work is done, lighted by conventional methods with reasonably uniform illumination, the relationship of the task brightness to the adaptation level is determined mainly by the reflection factors involved, and apparent brightnesses vary to a lesser degree than the absolute levels of illumination and luminance. Visual performance does, however, depend upon the absolute level, particularly when critical seeing and concentration of attention is involved; much work, particularly by Weston, has been devoted to the determination of the desirable absolute values for different kinds of visual task and performance, assuming ranges of usual conditions. This work has resulted in lighting codes which have been published in various countries prescribing appropriate illumination levels. At the 1951 Stockholm meeting of the C.I.E. it was recommended that national committees should study the work of Weston as a basis for such codes, and further codes have appeared on this basis.

Hitherto it has been possible thus to include the effects of adaptation by convenient approximations and assumptions; it may be that when its effects are more clearly understood, there may be further developments in the specification of the necessary absolute levels in given situations.

(2.3) Emphasis and Contrast

(2.3.1) *Emphasis and Centres of Attraction*

A reflex mechanism tends to draw the gaze to the brightest, most contrasty and most colourful things in the field of view. This fixation reflex, which is here called "phototropism," can be made to work to good account by suitable arrangement of the distribution of light on the main centres of attraction and on the surroundings, and by regulating their reflection factors and colours. The eyes can be attracted to their job, or to the natural focus of interest, if that is what is required, or they can be permitted to wander about with nothing in particular to attract their attention. Most seeing tasks require lighting which gives an effect between those two extremes. The greater the brightness of the main centre of attraction relative to that of the surroundings, the more will the attention tend to be held.

By controlled lighting or by control of reflection factor and colour, or by the three means in combination, a phototropic effect can be achieved.

This effect is used instinctively in certain branches of lighting; for example, on the stage, in show windows, in churches and in lecture rooms and concert halls. The principle could well be extended.

It is important to recognise that there can be no emphasis unless some parts of the scene are subdued; to make everything bright is to lose all emphasis and interest. This could arise from too literal an interpretation of the current recommendations of the S.Q.Q. Committee of the American Illuminating Engineering Society.

(2.3.2) *The Grading of Brightness and Contrast*

The immediate surroundings to an object of regard influence markedly the degree of comfort associated with seeing. If the object contrasts markedly with the surroundings, with a sharp boundary, the effect is irritating and uncomfortable; but if the luminance or colour of the object of regard is graded gently into that of the surround or background, a more satisfactory effect results.

Suitable relations have been found experimentally between the size of the visual task, the size of the immediate surroundings, the brightness of which should grade that of the task into that of the general scene, and the brightnesses of the task, the immediate surround and the general surround. Application of these principles has been found to enhance visual comfort.

(2.4) The Surroundings: Distraction and Glare

If the surroundings to the object of regard are not to be obtrusive, care has to be taken to avoid excessive brightness differences between different parts of the surroundings, otherwise excessive contrasts will draw attention from the designed centre of attraction. Excessive brightness range in the limit causes discomfort due to glare. The control of glare involves the general limitation of the brightness diversity in the field of view, and, in particular, a limitation of the brightness of any visible source of light or illuminated shiny surface in relation both to the average brightness of the field in which it is seen and to its angular separation from the principal directions of view.

The discomfort due to glare is a function of the brightness of the source of glare, its apparent size, its position in the field of view and the brightness of the surroundings. The higher the general brightness of the surroundings the less must be the ratio between the brightness of the source and of the surroundings if glare is to be avoided. This is partly because the highest brightness which the eye can tolerate lies closer above the adaptation level the higher that level is (see section 2.1) and partly because the eye cannot in any case adapt in comfort to an average luminance above a certain upper limit. This upper limit varies with individuals, but usually lies between that of a bright sky with light clouds and that of white concrete in full sunlight. The nearer the adaptation level approaches this upper limit, the greater the care that must be taken in controlling the brightnesses of the light sources. The remarks which apply to the grading of the contrast of the visual task to that of its surroundings apply equally to the grading of the brightness contrast of the light source to its immediate surroundings. Contrast grading is not, however, a universal palliative: it will not work when the brightness of the light source is of the order of the upper limit referred to above, and it works more effectively with small than with large sources.

The relationships between source and surround brightness, source size, shape and position have been studied in detail by several workers, notably Nutting, Ward Harrison, Luckeish and Guth, Hopkinson and Petherbridge and de Boer. Their results are found to be generally in agreement; design rules have been devised by some of them, and discussions have taken place with a view to producing rules co-ordinated from all the work. Logan and the S.Q.Q. Committee of the American Illuminating Engineering Society have recommended limits of the brightness range with the object of avoiding discomfort.

When the eye receives a relatively large amount of light from the surroundings, there may result not merely discomfort, but glare disability or reduction in ability to perceive the less conspicuous features of the field. This effect has been studied in detail by Holladay and by Stiles and Crawford; it obeys somewhat different laws from discomfort glare. It is greatest in the immediate vicinity of the bright source of light; and in reasonably well-designed interior lighting installations, true disability rarely occurs in significant amount, partly because the light sources are not usually located near the objects of regard, and partly because conditions giving rise to appreciable disability would cause severe discomfort and are, therefore, usually avoided. In daylight, however, with side lighted rooms, disability glare can occur in the immediate vicinity of the windows without the accompaniment of so great discomfort because the light source is very large; and recent work has demonstrated means for reducing the effect.

(2.5) Modelling and Shadows and the Revealing of Architecture and Form

(2.5.1) *General*

One function of interior lighting is to reveal appropriately the architecture, the furniture and the people in a room. The lighting must be thought of as an integral part of the architecture, for if there were no light there would be no architecture, for it has been said that architecture resides in the significant interplay of light and the forms created by the architects. There are aesthetic aspects of lighting design which do not conform to rules; an inspired design may produce a satisfying result although it may offend accepted rules. Nevertheless, there is much to be learned from the interplay of light and form.

Form and texture of objects are revealed by a complex distribution of luminance and colour, interpreted from long experience. The surfaces of architecture and objects receive light in amounts which vary with the direction from which it comes, according to the variation in the brightness field. Consequently the illumination of surfaces varies with their orientation, which produces an effect of modelling. Shadows are also cast by one part upon another. These two effects together produce a "structure pattern," i.e., a luminance pattern determined by the forms of objects. If the objects are not matt, further modification of the structure pattern occurs dependent upon the reflection properties of the object and the luminance field that it can see; this modification may be called the "texture pattern."

The structure pattern and the texture pattern thus arise from a combination of the luminance field seen by the object, the resulting distribution of illumination in space at the object, and of the form and reflection properties of the object: the detailed pattern is extremely complex.

(2.5.2) *Modelling and Cast Shadows*

In this Report the "modelling effects" of light are distinguished from effects due to cast shadow. *Cast shadow* occurs when the illumination of one part of a surface is reduced because another object, or another part of the same object, is interposed between the surface and a source of light. Cast shadow may have an abrupt edge or one so soft as to be imperceptible, depending on the relative subtenses of the shadow-caster and the source of light. "Modelling" at a point results from the change of illumination on a small surface element as it is turned in different directions; modelling can occur without the formation of cast shadow on the object. Modelling could be expressed as the rate of change of illumination with respect to orientation, though other expressions may be more useful.

It is convenient to distinguish modelling in azimuth and in altitude. Modelling in azimuth is the change in illumination occurring as a surface element, not horizontal, rotates about a vertical axis; modelling in altitude is the change of illumination occurring as a surface element rotates about a horizontal axis.

(2.5.3) *Modelling in Daylight Outdoors*

In daylight outdoors the modelling properties of the spatial illumination distribution are characteristically different in sunny and in overcast weather. On an overcast day there is fairly strong modelling in altitude—a horizontal surface facing upwards receives most illumination and one facing downwards receives least, the illumination diminishing progressively as a surface element rotates between these extremes. There is little azimuth modelling, i.e. the illumination on an inclined surface element changes little as it is rotated about a vertical axis. On an overcast day with snow on the ground there is little modelling of any kind.*

In sunlight in temperate latitudes, however, there is marked modelling in azimuth

* There is also an intangible quality known to some architects as "tone value," occurring particularly outdoors. Different "tone values" can occur on parallel planes receiving the same amount and distribution of light, so that modelling properties are not involved. Tone value may be a composite of light, colour, contrast and distance.

and much less in altitude; the maximum illumination occurs on a surface nearly normal to the incident sunlight, not on a horizontal surface.

(2.5.4) *Modelling Preferred in Interiors*

There is some evidence that people prefer in interiors a distribution of light which gives marked modelling in azimuth, and that they consider a distribution lacking modelling in azimuth to be flat and dull even when there is marked modelling in altitude. Lighting for the stage and studio confirms this; it is interesting that the preferred type of modelling corresponds to that outdoors in sunlight, and that an effect which we consider flat and dull indoors is very like what occurs on an overcast day.

(2.5.5) *Interior Modelling by Daylight and Artificial Light*

Many interiors appear quite different by night and by day, and the architect can hardly be equally satisfied in both conditions. The appearance is, of course, greatly affected by the view through the windows by day, but the effect still occurs when the view cannot be seen. The difference is usually pronounced in rooms lit by side windows and less pronounced when skylights are used alone by day. In side-lit rooms daylight flows more or less coherently across the room from the window walls, and produces marked modelling in azimuth which changes slowly and regularly over the interior. Maximum illumination is often on nearly vertical surfaces. Cast shadows are soft but are formed in a regular and coherent system. Large architectural features are usually clearly and coherently revealed by the structure pattern due to modelling and shadows. The pattern of luminance sometimes seems to be determined by form and texture rather than by the reflection factors of surfaces.

The same interior lighted by a pattern of artificial light sources suspended within it usually shows little modelling in azimuth, but strong modelling in altitude. There are directional effects near a light source, but the flow of light in the whole interior is incoherent, and the orientation of maximum illumination on vertical surfaces (which form the greater part of the field of view) varies almost at random. Objects usually cast multiple shadows at orientations and strengths which vary widely with the position in the room. Large architectural features are usually much less markedly and less coherently revealed than by day, and their true form is sometimes concealed. The pattern of luminance tends sometimes to depend more on reflection factors of surfaces than on their form or texture.

(2.5.6) *Interdependence of Modelling and Cast Shadows*

The features of the lighting which give rise to shadows and those which produce modelling are clearly related, and in some degree the one cannot be produced without the other. There is, however, considerable latitude; for modelling is found to be only slightly dependent on the subtense of the light source, whereas the sharpness of shadows depends markedly on it. By judicious use of large light sources, modelling may be produced with cast shadows so soft as to be imperceptible; conversely, using multiple bright sources, strong shadows may be formed with little true modelling effect.

(2.5.7) *Modelling and Glare*

Since modelling in azimuth requires a predominant source of light on one side of the interior, it cannot be achieved without some tendency to cause glare. However, by making the light source large and of low luminance, and by locating it skilfully, the glare may be imperceptible. It is much more difficult to achieve good modelling in interior lighting than it is in stage and photographic lighting, where glare is of little consequence. It is more easily achieved in interiors in which users all face in

one direction, as in many auditoria and churches, than in rooms in which users look in all directions. Evidently a good deal of study is needed to harmonise the two requirements.

(2.6) Colour and Decoration

In the design of the visual field decoration is as important as the lighting, and the two must be considered together. Decorations have two series of effects associated respectively with their reflection factors and their colours.

(2.6.1.) *Effects of Reflection Factors*

The most important effect of the reflection factor of a feature is to determine directly its relative luminance. By the use of decoration alone, certain parts of an interior can be made brighter than the remainder; similarly, architectural features can be emphasised or suppressed at will. Backgrounds appropriate to the revealing of people and objects can be formed; the latter effects can be produced by the use of colour as well as of reflection factor. Thus, the reflection factors of decorations are the principal means of determining the luminance pattern of the interior, upon which all the other effects depend, including adaptation, emphasis and comfort. Other effects of reflection factor are discussed in Section 3.1.1 below.

(2.6.2) *Effects of Colour*

The effects of decoration colours are very largely aesthetic and are subtle; they concern mainly the architect. Recent work in the design of schools and factories has produced some beautiful interiors, even in such unlikely places as foundries. The effect upon users of a well-designed colour scheme can be profound, over and above its effects on illumination and brightness; there is urgent need for further study of its possibilities.

(2.6.3) *Effect of Interreflection on Colour*

Interreflection of light in an interior affects the chromaticity of the reflected light as well as the luminance; the colour of the light reflected from the walls is more highly saturated than that of a flat sample similarly painted. This is due to a change in the spectral composition of the light caused by repeated reflection at selectively absorbing surfaces and the effect can be very pronounced in an enclosure with sides all painted a pastel colour. In a room in which only the walls are painted the interreflection effect is less, and it is complicated by the presence of the ceiling and other differently coloured surfaces. Nevertheless, the colours of the wall surfaces are generally more saturated and possibly of slightly different hue compared with the same surface receiving direct light only, and moreover the differences are not uniform throughout the interior. These effects are greater as the room is smaller, because in a small room the walls occupy a greater proportion of the interior surface.

(2.6.4) *Colour Constancy*

The effects called "brightness constancy" and "colour constancy" are being studied. These arise from the tendency of the eyes to make allowance for expected changes in the quality or amount of illumination. Thus the chromaticity of a uniformly painted side wall of a room will change from near the window to near the back of the room, in dominent wavelength and in purity, and the absolute luminance will change because of the change in illumination. By the subjective effects of "colour constancy" and "brightness constancy," observers allow for these real changes, and they appreciate the wall as being of constant colour and luminosity unless the constancy effect is deliberately upset by introducing some feature to break the continuity of the wall, such as a wall panel or door of different colour, or a band of white or some other strong colour. If this break is made, the colour constancy effect is broken and the two parts of a uniformly painted wall may give two different colour sensations.

The investigation of this phenomenon is at present in an early stage but it is considered of major importance by architects concerned with the design of interior decorations.

(2.6.5) *Effect of Colour of Light on Decoration*

The colour of light from the lamps can profoundly affect the appearance of the colour of the decorations and of the contents of an interior. There has been much recent work on colour adaptation; i.e., the phenomenon according to which the eye shifts its "white point" in the direction of the dominant hue of the illuminant. These phenomena are beginning to be understood, but their implications in lighting and decorating practice have yet to be worked out. They affect the choice of colours for illuminants, and the respective parts played by the colour of the light and the colours of the decorations in the design of the visual field.

Part III: The Formation of the Brightness Pattern and its Predetermination

(3.1) The Brightness Pattern

The visual attributes of an interior result from its brightness pattern. Studies now proceeding on visual comfort, emphasis, concentration and the revealing of architecture involve the brightness pattern in greater detail than has hitherto been considered, and it is desirable, therefore, to devise methods of predetermining the brightness pattern in any interior in the detail which such studies demand. This involves the brightness of relatively small areas, subtending only a few degrees of the visual field, whereas up to the present, studies have been concerned with larger zones or with average brightnesses of whole ceilings, walls, etc.

(3.1.1) *Analysis of the Problem*

The brightness of any surface depends upon two factors: (i) its illumination, and (ii) its reflection characteristics.

The illumination of the surface is determined by the flow of light to it from every direction, which in turn is determined by the brightness pattern of the whole interior. The illumination at any point can conveniently be considered as consisting of two components: E_d, the illumination received directly from the lighting equipment, and E_i, the illumination received by reflection and interreflection from all other surfaces in the interior. Thus the reflection properties of each surface play several parts:—

(i) They determine directly the luminance of the surface.

(ii) They affect the direct contribution which that surface makes to the illumination of others.

(iii) They affect the interreflection characteristics of the room.

The relative importance of the two components E_d and E_i depends upon the conditions in the interior. The greater the concentration of light flux upon the surface considered the more significant E_d becomes relative to E_i; conversely, as the light flux is more uniformly distributed in space the contribution of E_i increases relative to E_d. The higher the reflection factors of walls, ceiling, etc., the more significant E_i becomes; at high reflection factors this term increases rapidly and at the same time becomes increasingly sensitive to changes in reflection factor.

The value of the E_i component is likely to be nearly constant throughout an interior if there are no marked differences in the reflection factors of all major surfaces. The effect of differences in reflection factors on the spatial distribution of interreflected flux has not been fully investigated, but it is likely that if these factors differ widely, the component E_i will vary in different parts of the interior, particularly if the illumination considered is that on vertical surfaces facing the region of the different luminance.

If the surface is not flat, the brightness pattern which it presents is further complicated by effects of orientation and of shadow and, if the surface is not matt, by effects due to its reflection properties (see Section 2.5.1). These factors introduce complications of such magnitude that their detailed calculation becomes hopelessly

involved, though they are being studied qualitatively. The study of quantitative brightness must therefore at present be restricted to methods of predetermining, in somewhat idealised conditions, the illumination on surfaces such as flat walls, floor and ceiling in a rectangular interior, and of their resulting luminances if matt. For this purpose it is clearly necessary to pay equal attention to the predetermination of the direct and the interreflected components of light flux on interior surfaces.

(3.1.2) *Building up the Brightness Pattern*

Hitherto, predetermination of illumination has proceeded either as the calculation of the direct illumination from the lighting equipment using the "point-by-point" method, or calculation of average illumination due to both direct and interreflected light by the flux method, in each case on a hypothetical horizontal working plane. Calculations by the flux method have very largely neglected diversity factor and have been related to an average illumination only. The resulting brightness pattern was fortuitous or, at best, reflected the experience and imagination of the designer. Illumination on a horizontal plane will continue to be the starting point for the design of industrial, office and similar lighting installations, since it is the most convenient method of ensuring satisfactory task brightness, but it is not necessarily the best start for architectural and display lighting. Nevertheless the process of producing an acceptable brightness pattern will certainly involve the illumination. The introduction of interreflection tables has not changed the design procedure fundamentally but has made possible more exact predetermination of the general appearance of the room, and improved the prospect of ensuring comfortable lighting. The design procedure advocated in the American I.E.S. Handbook now includes a final stage in which the design, by the lumen method, is subjected to a brightness ratio check by the use of interreflection tables.

In order to satisfy the more precise requirements of brightness distribution which are foreshadowed by studies now in hand, the following design stages have to be envisaged :—

(i) Specification of the desired brightness pattern, from considerations of emphasis, visual tasks, modelling and comfort.
(ii) Preliminary lighting design by conventional methods with assumed or actual average reflection factors of walls and ceiling.
(iii) Determination of direct illumination (E_d) on interior surfaces chosen with regard to the requirements of emphasis, comfort, etc.
(iv) Determination of the interreflected component of illumination (E_i) on the same surfaces. (See Section 3.3.4.)
(v) Determination of the overall illumination of each selected area by combining (iii) and (iv).
(vi) Calculation of luminance pattern from the illumination and luminance factors.
(vii) Glare check by analysis of light source/background relationships by methods of Ward Harrison or Hopkinson.
(viii) Modification of luminance factors and lighting design where necessary to achieve the desired brightness pattern or degree of comfort.

(3.2) Predetermination of Directly Received Flux on Surfaces

Coradeschi and Innis in 1948 reported on a procedure for applying the basic interreflection tables to commercial lighting installations by calculating the relative flux contribution direct from the fittings array to ceiling, walls and floor and deriving from various room brightnesses from the basic tables by superposition. They showed that it was possible to obtain calculated figures reasonably consistent with actual results, but the procedure was laborious and there is clearly a need for simplification. A different form of presentation of photometric data may be possible by which the proportion of total flux emitted from the lighting equipment included in various zones around the

fitting is specified, rather than, as at present, distributions of luminous intensity or illumination portrayed in polar curves or Isophot diagrams. Alternatively, Brazington is testing the practicability of using Isocandela data for this purpose.

There are technical and practical difficulties in presenting the light distribution of fittings by the Sector flux method or as an Isocandela diagram. The direct component of the illumination nevertheless deserves further study and may become more important as the requirements of the brightness pattern are better understood. Perhaps tables could be produced which would enable the flux received by defined surface areas to be read off, from the positions of the fittings in the interior and their light distribution in terms of Sector flux.

(3.3) Interreflection

(3.3.1) *General*

The offset of interreflection on interior illumination has, until recently, been considered mainly in relation to illumination on horizontal surfaces, via empirical Utilization Factors. Mathematically based interreflection tables computed by D. E. Spencer were introduced by the S.Q.Q. Committee of the American I.E.S. in 1946. These tables provide data for the calculation of the average brightnesses of ceilings, walls (upper and middle) and floor in three special cases of room lighting :—

All light from ceiling.
All light from walls.
All light from the floor.

With these tables the average brightnesses resulting from any lighting installation may be calculated provided that the proportion of total flux sent to the ceiling, walls and floor is known. In Report No. 4 of the S.Q.Q. Committee a further set of tables was introduced, based on typical distribution characteristics of various forms of lighting. This obviated the need to calculate the wall, ceiling and floor components separately and add them together to obtain the result. The American I.E.S. Handbook also includes interreflection tables which are further simplified and which are designed to enable routine checks of average brightness ratios of proposed lighting installations.

The latter two sets of tables include tables giving values of (flux to working plane)/(flux from fittings) which are analogous to the standard coefficient of utilisation tables, except that they take no account of fittings light output ratio. These tables are mathematically based and take into account the floor reflection factor.

(3.3.2) *Validity of Interreflection Tables*

Spencer's interreflection tables are based on the premises of perfectly diffuse surfaces, each of uniform reflectance, and a ceiling of uniform luminance. The effect of the deviation of practical conditions from these assumptions is not fully established, although some practical checks have been carried out. There is scope for further examination, either by models or by measurements on actual installations, of the validity of the tables to all the diverse conditions met with in practice, and also of the variations produced by the introduction of equipment and people in a room. There is also scope for further mathematical treatment of complicated cases with a view to systematising deviations from assumed conditions.

(3.3.3) *Application of Interreflection Method*

The figures of brightness obtained from interreflection tables as at present used give no indication of localised brightnesses, but only the average brightness of large areas, i.e., their total flux emission.

The data cannot be interpreted as a brightness pattern but only as a generalised pattern of flux distribution (which could, in fact, arise from a great variety of brightness patterns).

In general it seems that interreflection data tables in their present form are a

useful addition to present design data but are not a complete solution to the problem of organising brightness patterns in interiors.

(3.3.4) *Presentation of Interreflection Data*

The present tables give the data in the form of average luminance of surfaces with a defined average reflection factor. The data could equally well be given in the form of zonal average illumination from which the luminance could be derived at any point having regard to the actual reflection factor at that point. This form of presentation appears to be receiving consideration in America and is more applicable to the role of interreflection data as suggested in Section 3.1.2.

(3.3.5) *Recent Work*

There has been surprisingly little systematic work done on the use of interreflection tables since 1947. Churchill and Putnam have worked on the verification of the tables by means of model studies. Brazington is at present investigating the use of the basic tables and the practicability of their application by measuring the flux distribution in a room with various combinations of non-reflecting and reflecting surfaces. Logan has been using interreflection tables commercially. Jones and Neidhart have worked on a zonal method of computing coefficients of utilisation and illumination on room surfaces which appears to be related to the suggestion in Section 3.3.4.

Conclusion

This report has reviewed some of the principal phenomena which arise in the lighting of an interior, and has indicated their interrelations and the extent of our quantitative understanding of them. It has drawn attention to some of the directions in which future work can be usefully done; it has looked at some of the other pieces of the puzzle, only two of which were given initially.

At this point it is well to consider what may be able to be done if all the pieces are available and can be fitted together; if all the features of the visual field can be measured, prescribed, predicted and provided on established principles.

Even if all the phenomena concerned could be so nicely defined, and if they could be exploited together without a serious clash of requirements—both of which suppositions are most unlikely—it is not to be supposed that a set of rules could ever be formulated, however well grounded, from which an outstanding design would emerge. In the final design architecture, furniture, decoration, colour and light will be compounded together into an aesthetically satisfying whole, and the design must result from combining the skills of the artist understanding technical means and materials and of the engineer appreciating the artistic aims. If some rules and limits emerge from the work here outlined, they must be used as clues to the artist-designer and as aids to the engineering of his design, rather than as regulations or codes compliance with which will secure a good result. There have been many attempts to shackle art with rules, but genius always breaks them; the art of designing the whole visual field is not likely to be an exception.

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